Mobile Gateway for Wireless Sensor Networks utilizing drones

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***Abstract*—Mobile Gateway for Wireless Sensor Networks utilizing drones**

Wireless Sensor Networks have good uses in applications running in remote locations, where maintenance is difficult. Wireless sensor network islands often need a connection with a gateway in order to communicate with the outside world, but this cannot be provided in all circumstances. A different approach to connecting wireless sensor networks is to use mobile gateways that can reach the remote locations where sensor devices are running. Our design includes a gateway mounted on an unmanned aircraft that collects data on its flight path.

***Index Terms*—gateway, wireless sensor networks, drone**

I. Introduction

Wireless Sensor Networks (WSNs) are being used more and more in almost every field imaginable. Applications generally involve collection and processing of data, either on-site or remote. Applications fields include home automation, agriculture, military, space exploration etc.[2] In order to collect the data, gateway platforms [8] are required and most of them are stationary bulky devices or PCs connected to one of the wireless nodes that serve as a base-station. Deployment in more remote locations with these gateways is very difficult at best and impossible at worst.

We aim to show in this paper that there exists a solution for a truly mobile gateway design that can be used either for collecting data or for debugging large wireless network infrastructures. Our solution involves a system that includes a high-mobility device (such as a quadcopter drone) and a WSN island comprised of nodes that collect data, but are able to store a limited amount of data until the data can be forwarded to the mobile gateway.[9]

The assumptions we make for the WSN are that of an actual deployment of nodes: We have a multitude of sensors platforms monitoring atmospheric conditions at fixed time intervals, that maintain a very low duty cycle: the period of activity, in which the node measures or transmits/listens on the radio, is less than 0.1%. This makes routing almost impossible, since the time it takes the aircraft to leave the transmission range is much smaller than the time it would take to propagate a package along one single hop. Routing is also prohibitively difficult in this scenario because of high storage demands: if an aircraft passes by once per day, every node has collected measurements ready to forward that make up a large portion of the available memory of each node. The gateway, on the other hand, can be a more sophisticated device (such as the one we are using, running Linux and with plenty of storage for measurements), which enables it to collect everything the nodes have to offer.

The challenge in this scenario is establishing a communication link with every sensor node, by being at the correct location at the right time. Our system does not assume that the sensor platforms are in range of one another but can handle the situation in which they do, by establishing individual communication links with each one at every fly-by. This is less taxing on individual sensor platforms, as they do not have to route packages. Our assumption for shifting the energy usage towards the gateway takes into account that radio communication is a very small percentage of the power used by an aircraft while flying.

We will show an overview of the system architecture in Chapter III, the hardware and software implementation in Chapter IV and results of using the gateway in Chapter V. We also take into account work already done on the subject in Chapter II.

II. Related Work

Research has been done in the area of wireless sensor networks with mobile gateways, but none include the same constraints as in our networks. Where most research focuses on routing packets to a mobile sink, we consider applications where network lifetime and low-maintenance are more important, and as such energy consumption on the nodes must be kept to a minimum (in order to have 3+ years of network lifetime with no maintenance/battery changes). Shifting the energy consumption to the sink is a direct consequence of this decision, under the assumption that there exists a flight path that allows the gateway to collect information from all the nodes.

Two-Tier Data Dissemination[10], Line-Based Dissemination[5] are protocols with mobile sinks for very specific networks. TTDD assumes sensor platforms are arranged in a perfect grid pattern, while LBD establishes a communication pattern over a virtual infrastructure, derived from the position of the nodes. Nodes in both protocols do not

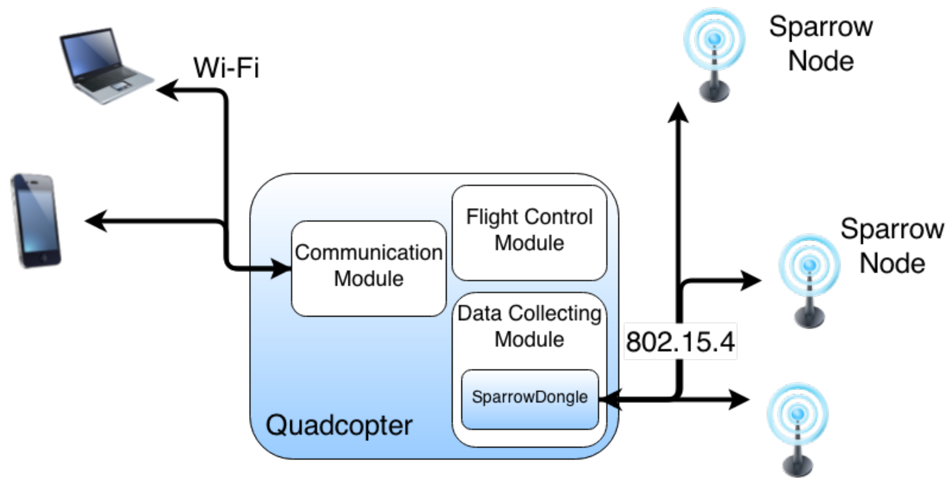

Figure 1. Modules and connections between them and devices

have duty-cycles in their activity and have either fixed-pattern positions or have GPS or equivalent equipped. This is very different from the small, energy constrained sensor platforms we wish to use and the mechanisms used by these protocols are not applicable in our system.

Another type of mobile sink system involves proactive routing as a variation to the directed diffusion protocol[6], such as XYLS[4], which disseminates data reports in two geographically-opposite directions, such that it intersects a corresponding data query. This is once again a system which offers a query system to a mobile sink, but cannot offer the collection of all measured data since its last fly-by.

III. System architecture

The classic way of implementing a gateway is by using stationary devices or mobile devices like laptops or phones connected to at least one wireless node. The problem with this type of mobile devices is that you have to be in close proximity of the node in order to communicate with it. This might not be a problem if the nodes are easily accessible, but if a node is located in a remote location (e.g. at a high altitude or over a cliff, or even at an unknown location), using drones seems to be the best alternative.

Having this to say, our design has a number of features useful in everyday interaction with a wireless node outlined in III-A,III-B.

They can be launched from anywhere, fly to any place a node might be placed, gather all the information collected by the nodes and even air-drop nodes.

A number of design features were included for ease-of-use in research and development, outlined in III-C,III-D.

A. *Ease of interaction*

The drone automatically detects and initiates a communication with a nearby node. It searches permanently for any signal emitted by a node and sends an acknowledgement packet back to it when it receives any signal. After this first handshake is complete, the node has green light to transmit the information to the gateway installed on the drone. If a node has been detected, the pilot is informed of its presence or if the data transaction completed successfully so that he may continue in the search for another node.

B. *Proximity function*

The SparrowDongle can supply informations regarding the nearby nodes by reading the strength of the received signal. Using this information, the pilot can direct the drone closer to the nodes location, either for a faster transfer or to find its exact location[11].

Besides the signal strength offered by the SparrowDongle, the drone features an on-board camera with a resolution of 1280x720 pixels streaming at 30 fps. This is very useful in pin-pointing the exact location of a wireless sensor node.

C. *Energy Saver*

Due to the communication protocol implemented, the SparrowV3.2 node uses very little power when not connected to the drone. It broadcasts just a small packet at fixed intervals for low consumption and enters a high bandwidth mode when it detects the presence of a drone for a fast data transfer, similar to the solution described by Cardei et al. [3].

D. *Latest Data*

The data is stored on the flash micro controller of the node. In this way, the data is persistent in the memory even the power drops and can be recovered when the power is restored. When the memory is full, the oldest data is deleted in order to make space for new one. The data sent to the drone is from the oldest to the newest, so that in the event of a connection lost the node has free space for new data.

IV. Implementation

A. Hardware Details

Figure 3. SparrowDongle connected to AR Parrot Drone 2.0

The hardware components used are the following:

- a SparrowDongle with two micro controllers: The 8-bit ATMega128RFA1 which has an on-chip 2.4GHz wireless transceiver and the ATMega32U4, both from Atmel.
- a SparrowV3.2 with an ATMega128RFA1 micro controller
- a AR Parrot Drone v2.0
- a SAMSUNG Galaxy S4 with android 4.4.2, but a laptop or other mobile phones with android/ios can be used for controlling the drone

Because of the addition of the SparrowDongle, the drone's polyester hull has had to been carved a little in order to accommodate it.

B. Software Implementation

The parrot drone, with a Linux based operating system, allow the software to be organized in different modules. The modules can be modified individually to add more features to the system.

The SparrowDongle gateway dumps every data received on the serial. It is always in a listen for data state. When it receives the data, it sends back an ack to let the SparrowV3.2 node know that it can begin sending the entire data to the mobile gateway.

The SparrowV3.2 node is sending periodically a small data packet to check if a gateway is available. When it receives the ack for the packet it starts sending the stored data to the gateway. The data sent can vary, from sensor readings, to debugging informations in order to check the state of the Wireless Sensor Network.

The data gathered by the gateway is saved into different files the AR Parrot Drone's internal memory. The file also contains informations about the node identification tag and time of the transfer. The data can be accessed at any time by any device connected to the drone's wireless network via FTP.

All the collected data is processed on the drone. It awaits a socket connection in order to start sending informations regarding the state of the connected nodes.

The nodes can be programmed to determine the signal strength of the surrounding nodes. This data is sent to the drone in order to determine the approximate location of the nodes[7].

V. Results

In this chapter we will cover the results obtained with this gateway platform.

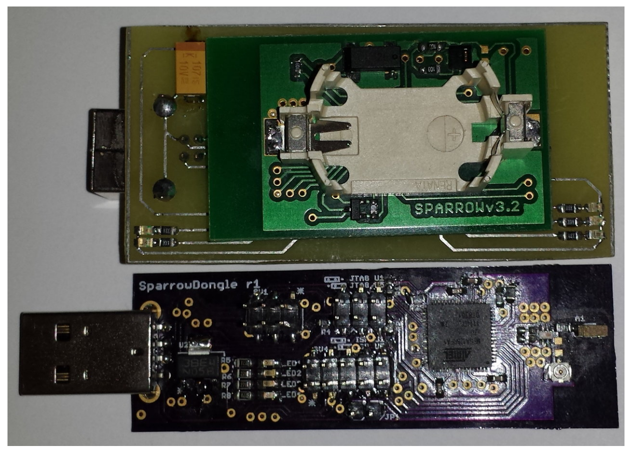

Figure 4. SparrowV3.2 and SparrowDongle

A. Performance

The platform can detect multiple wireless sensors and offer real time feedback. The delay is small, but it can vary directly proportional with the distance between the drone and the phone and between the drone and sensor. Usually this delay can start from 10 ms and pass 150ms for high distance connection. Also, thanks to the transmission speed of 250kbps, big data is transfered in under 3 seconds. After the transfer is complete, it can be uploaded to the remote sever for further processing.

B. Hardware

The dongle fits tightly between the body and the shell of the drone. This can represent a future problem on different types of drones where a smaller dongle may be required.

Because the drone has a powerful arm processor, it can do most of the processing required to fly and to detect and collect data from nodes. By using this approach, even when the drone loses connection to the mobile phone, it can hover on its own until the connection is reestablished.

Figure 2. FreeFlight 2.0 with added WSN capabilities

C. Software configurations

The software solution is very versatile. It can be ported on every platform and programing language that supports sockets, also the dongle and the nodes ca be reprogrammed following the application specifications in which they are used.

At the moment, the following modes of operation are available, but more are to follow:

- *Node discovery*: Nodes can be discovered and located easily when the drone is in proximity.
- *Data server*: This mode allows the drone to save the data and to be accessed even when the drone's power supply is removed or it is not flying or connected to any node
- *Debug Tool*: The drone can have a list of nodes that are located on it's flight course and can detect the node that is causing the network not to function properly.

VI. Future work

The versatility of the platform makes it ideal to be deployed in a wide range of applications, especially those of which environment is dynamic.

For instance, some possible applications in which the drone can be deployed are [1]:

- Autonomous collection of data data by adding a gps receiver to the drone and setting a path of way points to follow
- Debugging a wireless sensor network by checking which node is working, the connection logs and the physical state of the device
- Search and rescue operations, especially when going skiing in a avalanche prone environment by wearing a wireless sensor.
- Creating a small wireless sensor network for a limited time with small costs and large battery life
- Treasure hunt where the sensors can hold the clues that lead to the location of the treasure

VII. Conclusion

The paper presented an innovative mobile gateway platform for wireless sensor networks that offers the ability to interface sensor networks in a novel way.

The platform is easy-to-use and customize to meet the different needs of applications. The system is able to collect data from a Wireless Sensor Network island and offers a potential drone operator realtime data concerning nodes in proximity. The system uses the Parrot AR drone and is decoupled from the piloting module, allowing different piloting schemes to be used with it (i.e. the drone can be piloted anywhere, with or without an operator and it will collect data automatically).

References

[1] T. Arampatzis, J. Lygeros, and S. Manesis. A survey of applications of wireless sensors and wireless sensor networks. In *Intelligent Control, 2005. Proceedings of the 2005 IEEE International Symposium on, Mediterrean Conference on Control and Automation*, pages 719–724. IEEE, 2005.

[2] A. Baggio. Wireless sensor networks in precision agriculture. In *ACM Workshop on Real-World Wireless Sensor Networks (REALWSN 2005), Stockholm, Sweden*, 2005.

[3] M. Cardei and D.-Z. Du. Improving wireless sensor network lifetime through power aware organization. *Wireless Networks*, 11(3):333–340, 2005.

[4] S. M. Das, H. Pucha, and Y. C. Hu. Performance comparison of scalable location services for geographic ad hoc routing. In *INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings IEEE*, volume 2, pages 1228–1239. IEEE, 2005.

[5] E. B. Hamida and G. Chelius. A line-based data dissemination protocol for wireless sensor networks with mobile sink. In *Communications, 2008. ICC'08. IEEE International Conference on*, pages 2201–2205. IEEE, 2008.

[6] C. Intanagonwiwat, R. Govindan, and D. Estrin. Directed diffusion: a scalable and robust communication paradigm for sensor networks. In *Proceedings of the 6th annual international conference on Mobile computing and networking*, pages 56–67. ACM, 2000.

[7] C. Savarese, J. M. Rabaey, and J. Beutel. Location in distributed ad-hoc wireless sensor networks. In *Acoustics, Speech, and Signal Processing, 2001. Proceedings.(ICASSP'01). 2001 IEEE International Conference on*, volume 4, pages 2037–2040. IEEE, 2001.

[8] L. Steenkamp, S. Kaplan, and R. H. Wilkinson. Wireless sensor network gateway. In *AFRICON, 2009. AFRICON'09.*, pages 1–6. IEEE, 2009.

[9] J. Valente, D. Sanz, A. Barrientos, J. d. Cerro, Á. Ribeiro, and C. Rossi. An air-ground wireless sensor network for crop monitoring. *Sensors*, 11(6):6088–6108, 2011.

[10] F. Ye, H. Luo, J. Cheng, S. Lu, and L. Zhang. A two-tier data dissemination model for large-scale wireless sensor networks. In *Proceedings of the 8th annual international conference on Mobile computing and networking*, pages 148–159. ACM, 2002.

[11] K. Yedavalli, B. Krishnamachari, S. Ravula, and B. Srinivasan. Ecolocation: a sequence based technique for rf localization in wireless sensor networks. In *Proceedings of the 4th international symposium on Information processing in sensor networks*, page 38. IEEE Press, 2005.